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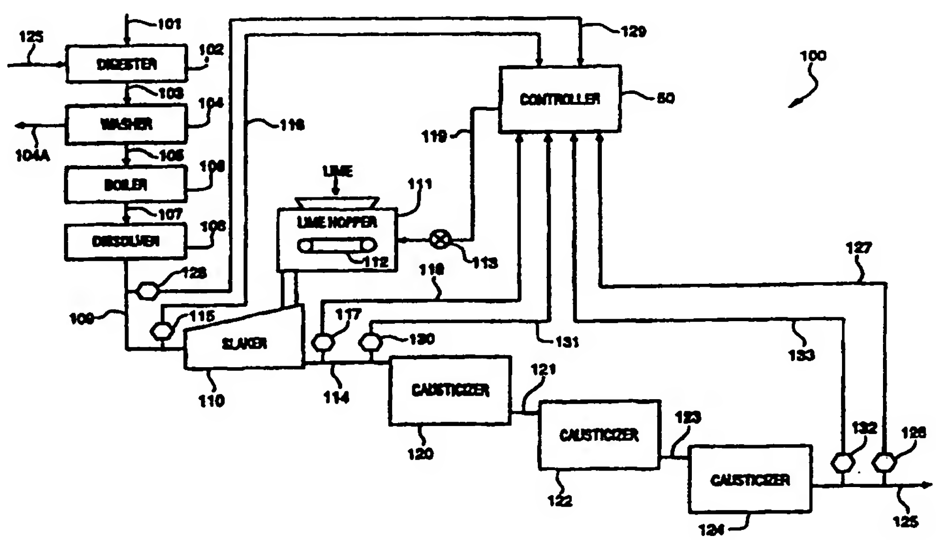

(57) Abstract

Continuous measurements are made of a characteristic of the individual components of green liquor fed to a slaker and white liquor exiting from the slaker. The liquor component measurements provide a precise characterization of the liquors allowing for a more efficient control of the causticizing reaction in the kraft process. The individual component measurements are provided as inputs, along with certain ambient measurements, to a non-linear controller. The controller produces a causticizing control signal which is used to control the amount of lime introduced to the slaker. The controller is adapted to a particular process installation through the application of data collected from that installation. The controller, for example a neural network or fuzzy logic controller, produces a causticizing control signal according to unique parameters developed for the specific installation.

PROCESS FOR CONTROLLING THE EFFICIENCY OF THE CAUSTICIZING PROCESS

FIELD OF THE INVENTION

The present invention relates to a control system for the control of the causticizing reaction as part of a kraft liquor processing system. Particularly, the present invention provides a method for measuring the components making up the input to the causticizing reaction, green liquor, and the components making up the product of the causticizing reaction, white liquor. The liquor component measurements are evaluated to produce a precise, non-linear control of the causticizing reaction.

STATEMENT OF THE PROBLEM

The kraft or sulphate process is the most widely used wood pulping process. The process is a circular one in that the chemicals used to achieve the desired processing steps are themselves recovered in later steps and reused in the process. The degree to which each step of the process occurs with the maximum efficiency greatly impacts the purity of the final white liquor as well as the cost of the overall process.

In the kraft process, wood chips are digested to dissolve the lignin that holds the wood fibers together thereby producing clean fibers for further processing into a myriad of paper-based products. The digestion of the wood chips occurs in an alkaline solution mainly consisting of NaOH ("hydroxide") and Na_2S ("sulfide"). As the process proceeds, the hydroxide is substantially consumed and the level of sulfide remains relatively unchanged. The resulting pulp fibers are washed and removed leaving a solution, called black liquor, containing the lignin dissolved from the wood chips and the residue hydroxide and sulfide. The black liquor is burned in a boiler leaving a smelt primarily consisting of sulfide and Na_2CO_3 ("carbonate"). This smelt is dissolved in water or "weak wash liquor" to produce green liquor. The objective of the remaining steps of the process is to convert the carbonate of the green liquor to hydroxide so that the hydroxide can be recycled and reused in the pulping process.

The reaction for converting the carbonate to hydroxide is often referred to as the "causticizing process" or the "causticizing reaction". The causticizing

are related to the progress of the causticizing reaction. The amount of lime introduced into the slaker is adjusted accordingly. White and gre n liquor are comprised of various components each of which has its own set of characteristics. A measurement of a single characteristic of the entire white or green liquor, as taught by Bertelsen, can result in error when the component characteristics vary in such a way that the combination of the component characteristics result in a total liquor characteristic measurement that masks the component characteristics. For example, green liquor has a small amount of hydroxide which contributes disproportionally to the conductivity measurement of the green liquor since the carbonate component of the green liquor has a relatively low conductivity. Thus, a relatively small variation in the amount of hydroxide in the green liquor results in a disproportionally significant change in the conductivity measurement of the green liquor. The opposite problem occurs on the other side of the causticizing reaction when measuring the conductivity of the white liquor. The Bertelsen method assumes that chemicals other than those of interest to the causticizing reaction are not present or do not vary in the measured liquors. This assumption is rarely true in practice and leads to errors in the Bertelsen measurement. The Bertels n method also relies on a rigid mathematical formulation based on the conductivity measurements even though there are multiple components of each of the liquors, each of which can vary independently.

There exists a need for a method of controlling the causticizing reaction for the production of white liquor that is responsive to the individual components of the green liquor and the white liquor. There exists a further need for a method of controlling the causticizing reaction that measures a characteristic of each relevant component of each of the liquors. There exists a further need for accomplishing the above in a system that continuously measures the stream of liquor as opposed to sampling the liquor stream. There exists a further need to combine the individual liquor component data to produce a non-linear control signal to optimize the efficiency of the causticizing reaction.

STATEMENT OF THE SOLUTION

The present invention solves the above and other problems, thereby advancing the useful arts, by providing methods and apparatus for controlling the

neural network is "trained" to produce the desired causticizing control signal for any given set of liquor component measurements input to the neural network. An installation-specific configuration of the neural network is thereby achieved.

In a further method of the present invention the controller, to which the liquor component measurement values are input, is comprised of a fuzzy logic controller. The fuzzy logic controller is tuned with the appropriate scaling factors to produce the desired causticizing control signal for any given set of liquor component measurements input to the fuzzy logic controller. An installation-specific configuration of the neural network is thereby achieved.

According to another aspect of the present invention, polarographic measurements are made to determine the concentration of each liquor compon nt in the various liquors. The component polarographic measurements made at each point in the process are input to the controller. The controller evaluates the liquor component polarographic measurements to produce the desired causticizing control signal. The causticizing control signal is used to adjust the rate of lime introduced to the slaker in which is occurring the causticizing reaction.

In a further embodiment of the present invention near-infrared spectroscopy measurements are made of the green and white liquor components. The near-infrared measurements made at each point in the process are input the controller. The controller evaluates the liquor component near-infrared measurements to produce the desired causticizing control signal. The causticizing control signal is used to adjust the rate of lime introduced to the slaker in which is occurring the causticizing reaction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic representation of a causticizing process according to the present invention.

FIG. 2 is a representative polarographic current-voltage curve for carbonate.

FIG. 3 is an absorbance spectra for different mixtures of liquor components.

FIG. 4 is a simplified schematic view of a neural network according to the present invention.

material is sequentially directed with the effect that the causticizing reaction is completed to a greater degree with ach causticization step. Th output of causticizer 124 in line 125 is the finished white liquor containing mainly NaOH as well as small amounts of Na_2CO_3 and Na_2S. The white liquor is conducted through line 125 back to digester 102.

Sensors 115, 117 and 126 generate signals, as described below with respect to FIGs. 1-3, which are transmitted over wires 116, 118 and 127, respectively, to controller 50. The signals generated by sensors 115, 117 and 126 are indicative of the amount of individual liquor components at the respective measurement points in process 100. Sensors 128, 130 and 132 generate ambient condition measurement signals, as described below with respect to FIGs. 1-3, which are transmitted over wires 129, 131 and 133, respectively to controller 50.

Causticization Process - FIG. 1

The green liquor input to slaker 110 over line 109 is characterized by a small content of NaOH and Na_2S and a large content of Na_2CO_3. In order to re-form th white liquor which is primarily comprised of NaOH for use in the digestion process, lime is added to the slaker along with the green liquor. The following reactions occur beginning in the slaker:

slaking reaction: $CaO + H_2O \rightarrow Ca\,(OH)_2$

causticizing reaction: $Ca\,(OH)_2 + Na_2CO_3 \rightleftharpoons 2NaOH + CaCO_3 \downarrow$

The slaking reaction is effectively the lime reacting with water to create calcium hydroxide. The calcium hydroxide then reacts with the carbonate in the causticizing reaction to form hydroxide. The term "causticizing reaction" is commonly used to refer to the process by which both of the above chemical reactions occur. The desired outcome of these reactions is to convert all of the Na_2CO_3 to NaOH although in practice this objective is never fully achieved. To encourage the above reactions to completion a series of causticizers, beginning with causticizer 120 of FIG. 1, are used to further convert Na_2CO_3 to NaOH. Each of causticizers 120, 122

invention. Two alternative embodiments utilizing different measurement technologies for determining the liquor component measurements are describ d below.

A measurement technology that is used to determine the relative concentrations of the individual liquor components is polarographic measurements. The basic concept behind polarographic measurements is the recognition that, for certain chemical components, there is a given voltage range over which the current flowing between electrodes of a measuring device placed in the solution varies from a small level, that is essentially independent of the voltage applied to the solution, up to an intermediary quasi-stable level that varies with the content of the component of interest in the liquor to a very high level that again is essentially independent of the voltage applied to the measuring device.

A polarographic measurement of a given component of a liquor involves obtaining repeated measurements of current-voltage points for voltages within a potential region of interest for that particular component. The various current-voltage measurements form a polarographic-current curve for the given component that can be compared to a similar curve for a solution having a known content of the given component to provide an indication of the content of the specific component.

An exemplary polarographic current-voltage curve 200 is illustrated in FIG. 2 for Na_2CO_3. Axis 202 represents the voltage applied to the Na2CO3-containing liquor. Axis 204 represents the amount of current flowing in the liquor between the electrodes of the polarographic measurement device. As shown in FIG. 2, as the voltage is varied from 0.2 V to 0.6 V, the current detected by the measuring device is minimal and the changes in the voltage level have little effect on the magnitude of the detected current. As the voltage reaches 0.6 V, however, the current begins to rise and reaches a quasi-stable level which is referred to as wave height 206. The magnitude of the current at this quasi-stable level corresponds to the cont nt of $Na_2 CO_3$ in the measured liquor. As the voltage increases further past 1.6 V, the current begins to increase rapidly. By comparing this wave height 206 for Na_2CO_3 with the wave heights obtained by taking similar measurements in a known solution having a known content of Na_2CO_3, the content of the Na_2CO_3 in the solution under

spectrometer. Axis 304 represents the absorbance of a particular wavelength of light by a particular solution. The units of axis 304 are referenced to the absorbance of the same wavelength of light by air. Absorbance spectra 300 is comprised of the overlaid spectra, 306-314, of five different solutions each having its own characteristic spectrum. The composition of the five solutions is summarized in the following table.

Spectrum 306	8.95% NaOH, 2% Na_2S, 3%Na_2CO_3
Spectrum 308	10%NaOH
Spectrum 310	9.3% Na_2S
Spectrum 312	9.9% Na_2CO_3
Spectrum 314	3%NaOH, 5% Na_2S, 3% Na_2CO_3

Spectra 306-314 are characteristic of the typical range of concentrations seen in the liquors of the causticization process. An analyzer such as the MLA 8100 Multiple Component Liquid Process Analyzer must be calibrated on solutions of materials having known concentrations of component chemicals. The measured absorbance spectra, determined at sensors 115, 117 and 126, are compared to the known spectra to determine the relative concentrations of NaOH, Na_2CO_3 and Na_2S in the liquors at the various measurement points. This comparison is most easily accomplished by utilizing look-up tables holding values characterizing the known spectra. There are various methods known to those skilled in the art for comparing a measured wave form to a family or spectra of known waveforms. The liquor component measurements signals are transmitted over lines 116, 118 and 127 to controller 50.

<u>Controller Operation - FIGs. 1,4-5</u>

The relationship between the individual liquor component measurements from sensors 115, 117 and 126 is complex and non-linear. Adding to the

implemented in the ISTK. Input layer 401, containing nodes 401A - 401N, receives input information in the form of the liquor component measurement data and the ambient measurement data. There is a node 401A - 401N for every measurement point input to controller 50 over lines 116, 118, 127, 129, 131, and 133. Note that each of the above signal lines represents more than one data path as, for example, line 116 may in–practice be three lines, one for each liquor component measurement. Output layer 403 contains a single node 403A from which the causticizing control signal is output over line 119. Intermediary layer 402, containing nodes 402A - 402N, may contain more nodes or less nodes depending on, but not limited to, the number of neurons in input layer 401, the level of accuracy required of neural network 400, and the number of neurons in output layer 403. The signals input to input layer 401 are assigned different "weights" by the input neurons 401A - 401N. These weighted intermediary signals are then applied as inputs to intermediary neurons 402A - 402N over neuron connectors 404. Intermediary neurons 402A - 402N each assign different weights to the various intermediary signals to produce a second set of intermediary signals. This second set of intermediary signals is applied to neuron 403A of output layer 403.

A neural network must be trained for a given application. The weights associated with each neuron are adjustable during training and are fixed after being trained. The training and implementation of a neural network, once the appropriate inputs have been selected, is known to those skilled in the art of advanced process control tools. In general, the first step is to assemble a database of historical data. In the present invention this historical database includes ambient measurement data and liquor component measurement data. The extent to which one must gather or create data prior to implementation of the neural network depends on the past practices in that facility with respect to process control methodology and data collection. In some plants, a sizable database will already exist, especially with respect to the ambient measurement data. In other plants it will be necessary to collect data for a time in order to assemble the necessary data for training the neural network. In most plants it will be necessary to collect individual component measurement data for neural net training purposes as this has not been one of the traditional measurements made in the causticizing process.

require that there be a m chanism responsive to the causticizing control signal for adjusting the rate of lime introduced to slaker 110.

Fuzzy Logic - FIG. 5

Another embodiment of non-linear, application adaptable controller 50 of the present invention utilizes a fuzzy logic controller 500 to process the liquor component measurement signals and the ambient measurement signals to produce an appropriate causticizing control signal. Fuzzy logic controllers, like neural networks, are particularly well suited for control of non-linear processes. Fuzzy logic controllers typically use a set of scaling factors associated with a set of membership functions to translate continuous input signals into fuzzy logic variables. A set of fuzzy logic inference rules are then applied to the fuzzy logic variables to determine an output fuzzy logic signal which is, in turn, converted into a continuous signal for use in controlling the process. Although the scaling factors can be determined in a number of ways, most fuzzy logic controllers determine the scaling factors from values developed from the process being controlled, i.e., form one or more process characteristics. The process of periodically measuring one or more process characteristics and developing a new set of scaling factors based on those process characteristics is referred to as tuning the controller.

Referring now to Fig. 5, a typical fuzzy logic controller 500 is generally described. Fuzzy logic controller 500 includes an input signal fuzzification block 502, a fuzzy engine block 504 and a defuzzification block 506. The fuzzification block 502 translates or transforms the inputs A through N into linguistic fuzzy variables, such as, for example, Positive Large, Negative Large, Zero, etc., with the use of so-called fuzzy membership functions. Likewise the defuzzification block 506 translates a fuzzy variable representing a chance in a control action into a continuous change in the causticization control signal with the use of fuzzy membership functions.

The fuzzy membership functions used in the fuzzification block 502 and the defuzzification block 506 may be defined based on prior knowledge about the process. Similarly to neural networks, a reliable database of expected measurement values is useful for tuning the fuzzy logic controller for use in a particular application or installation. The signals A through N are scaled so that

An example of one such commercially available package is the Intelligent S nsors Tool Kit (ISTK) available from Fisher-Rosemount Systems, Inc. of Austin, Texas.

As was described with respect to the neural network embodiment of controller 50, the causticization control signal is output from controller 50 over line 119. The causticization control signal determines the operation of actuator 113 which in turn controls the operation of lime conveyor 112 thereby providing th proper amount of lime from lime hopper 111 to slaker 110.

It is to be expressly understood that the claimed invention is not to be limited to the description of the preferred embodiment but encompasses other modifications and alterations within the scope and spirit of the inventive concept.

measuring a relative concentration of each of said white liquor components after said white liquor exits from a slaker.

6. The method according to claim 5 wherein said step of measuring a relative concentration includes:

obtaining ~~a~~ relative concentration measurement of each of said white liquor components from a near-infrared spectrometer positioned to provide said relative concentration measurements after said white liquor exits from said slaker.

7. The method according to claim 5 wherein said step of measuring a relative concentration includes:

obtaining a relative concentration measurement of each of said white liquor components from a polarographic measurement device positioned to provide said relative concentration measurements after said white liquor exits from said slaker.

8. The method according to claim 5 wherein said step of measuring said relative concentration includes:

measuring a first relative concentration of each of said white liquor components after said white liquor exits from said slaker; and

measuring a second relative concentration of each of said white liquor components after said white liquor exits from a causticizer.

9. The method of claim 1 wherein said step of evaluating said green liquor component characteristics and said white liquor component characteristics includes:

adapting said controller with an installation-specific configuration to optimize the production of white liquor in a specific installation;

transmitting said white liquor component characteristics and said green liquor component characteristics to an input stage of said controller; and

processing said white liquor component characteristics and said gr en liquor component characteristics to produce said causticizing control signal according to said installation-specific configuration of said controller.

14. An apparatus for controlling the causticizing reaction to produce a white liquor having multiple white liquor components from a green liquor having multiple green liquor components, said apparatus comprising:

a green liquor sensor for measuring a characteristic of each of said green liquor components;

a white liquor sensor for measuring a characteristic of each of said white liquor components;

a non-linear, application adaptable controller responsive to said green liquor component characteristics and said white liquor component characteristics for producing a causticizing control signal; and

means for controlling said causticizing reaction responsive to said causticization control signal to produce white liquor.

15. The apparatus according to claim 14 wherein said green liquor sensor comprises:

a relative concentration instrument for measuring a relative concentration of each of said green liquor components before said green liquor enters a slaker.

16. The apparatus according to claim 15 wherein said relative concentration instrument comprises:

a near-infrared spectrometer positioned to provide said relative concentration measurements before said green liquor enters said slaker.

17. The apparatus according to claim 15 wherein said relative concentration instrument comprises:

a polarographic measurement device positioned to provide said relative concentration measurements before said green liquor enters said slaker.

18. The apparatus according to claim 14 wherein said white liquor s nsor comprises:

23. The apparatus of claim 22 wherein said non-linear, application adaptable controller comprises a programmable neural network.

24. The apparatus of claim 22 wherein said non-linear, application adaptable controller comprises a programmable fuzzy logic controller.

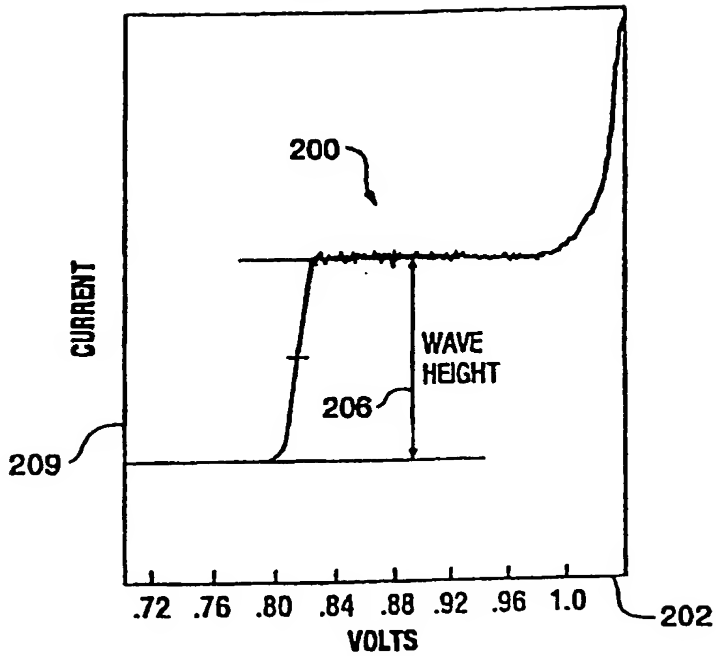
200
CURRENT
WAVE
HEIGHT
206
209
.72
.76
.80
.84
.88
.92
.96
1.0
202
VOLTS

FIG. 2

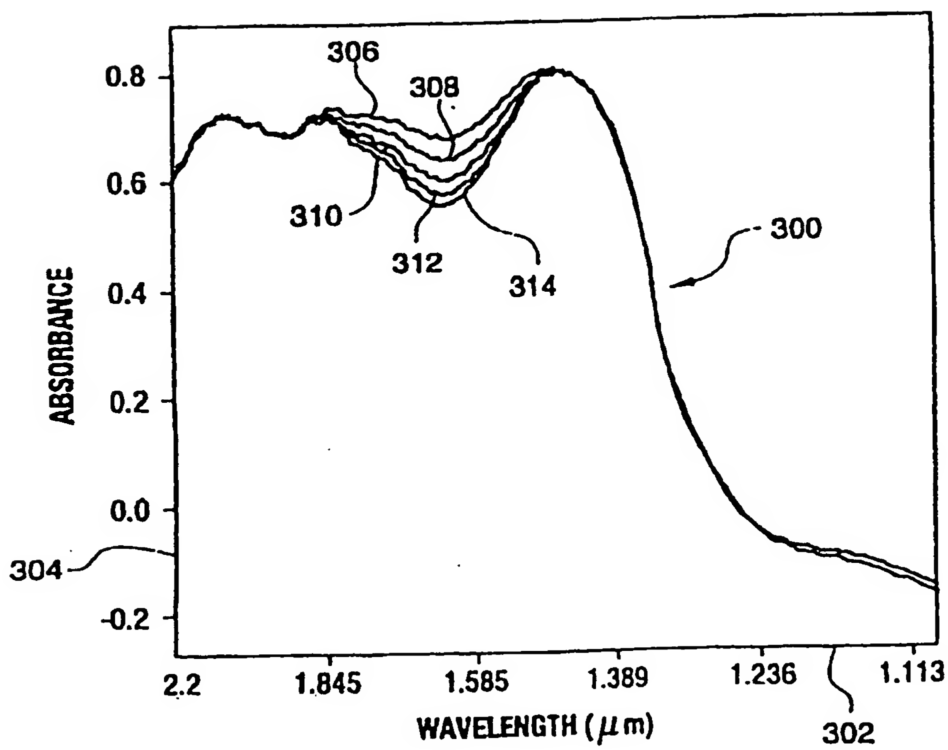
0.8
0.6
0.4
0.2
0.0
-0.2
ABSORBANCE
306
308
310
312
314
300
304
2.2
1.845
1.585
1.389
1.236
1.113
302
WAVELENGTH (μm)

FIG. 3

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 97/14645

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 D21C11/00 G05B13/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 D21C G05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 378 320 A (LECLERC DENYS F ET AL) 3 January 1995 see column 5, line 5 - column 6, line 8; claims ---	1-3,5,6, 9,12, 14-16, 18,19, 21,24

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
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"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
18 December 1997	14/01/1998

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

In tional Application No
PCT/US 97/14645

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